Biomonitoring under Changing Climate Conditions: Assessing Seasonal Variability of Benthic Macroinvertebrate Communities and Stream Characteristics in Two Ecozones in Northern Ontario, Canada

by

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Abstract

The vast “Ring of Fire” region, at the interface of the Boreal Shield and Hudson Plains ecozones in the far north of Ontario, Canada, is considered to be one of the most promising mineral exploration areas in Ontario in almost a century. The region is undeveloped and remote, accessible only by air, water or winter road. Multiple stresses to the natural ecosystems are anticipated with mining development, in a time of climate change which is predicted to significantly impact hydrological and temperature regimes (intensified spring freshet, more high discharge events, warmer temperatures for longer). Preserving and protecting the aquatic ecosystems in this pristine region will require effective baseline environmental monitoring in advance of development. Quantifying seasonal variation of habitat characteristics and benthic macroinvertebrate (BMI) communities, and assessing the seasonal difference between ecozones are considered key challenges in designing effective monitoring programs. In this study, I examined seasonal variability in habitat characteristics and BMI communities by sampling 43 stream sites distributed across the two ecozones. In 2015 each site was sampled three times during the open water season: post-freshet, mid-summer and fall. BMI communities varied among sampling seasons, but less variation was observed between the post-freshet and summer sampling periods than either of these compared to the fall. Ordination analyses of BMI communities identified to the family level indicated that sites from the same sampling season were more likely to group together. Water temperature, stream velocity and canopy coverage were the key factors associated with seasonal differences in benthic macroinvertebrates. Differences in location of the sampling sites across the two ecozones did not significantly impact seasonal variability, but differences may have been constrained by the common habitat features used because of the sampling protocol. Conducting sampling during the post-freshet or summer seasons is recommended for future stream bioassessments to reduce the influence of seasonal variability and thus ensure comparability over time.

Keywords: Seasonal Variability, Benthic Macroinvertebrates, Ecozones, Ring of Fire, Biomonitoring, Climate Change

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Introduction

The far north of Ontario is one of the world's largest relatively pristine ecosystems, providing important ecosystem services at both local (e.g. subsistence fisheries) and global (e.g. carbon sequestration) scales. This area is difficult to access (air, water and winter road) and currently has little industrial development. It is sparsely populated by First Nations peoples living in remote communities. A region within the far north of Ontario, known as the Ring of Fire (5,120km^2), has been a recent target for extensive mining exploration and has shown the potential to support a large multi-generational mining development with significant proven reserves of chromium, nickel, copper, vanadium, gold, zinc and platinum (Hjartarson et al. 2014). Development of the mineral resources in this region is expected to create a variety of infrastructure such as town sites, transportation corridors, power generation and distribution facilities with substantial potential for associated impacts on the environment (Far North Advisory Panel 2010). Concurrent with development, Ontario's far north is also projected to be disproportionately impacted by climate change (Gagnon and Gough 2005) because James Bay and Hudson Bay are experiencing rapid declines in sea ice that are leading to a substantial increase in regional temperatures (Hochheim and Barber 2010). Climate change projections forecast that the region will experience much longer and warmer summers, and particularly warmer winters. The altered winters are also anticipated to have more or perhaps more extreme precipitation events likely leading to more severe spring freshets (Colombo et al. 2007, McLaughlin and Webster 2013). Stream flow is expected to be increasingly variable and water temperature is expected to increase with air temperature (Far North Advisory Panel 2010). Recent paleolimnological studies have suggested that the climate of the far north of Ontario was largely protected from global changes by the buffering effect of the sea ice, but changes began rapidly in around 1995 (Rühland et al. 2013, Rühland et al. 2014).

The Ring of Fire is located at the transition between two ecozones; the Hudson Plains and the Boreal Shield (Figure 1) (Hjartarson et al. 2014). The Hudson Plains ecozone holds the world's 3rd largest wetland and the largest in North America (Riley 2011). It has low topographical relief and is comprised of a thick layer of peat with bogs and fens, creating highly interconnected drainage systems (Riley 2011, Orlova and Branfireun 2014). It is characterized by Paleozoic age sedimentary bedrock with quaternary glacial and marine deposits on the surface (Macleod et al. 2016). The Plains do however have some sloped, well drained areas, for example, along river valleys, where tributaries can enter as cobble-bottom streams. These drainage systems allows for forests to grow in the stream riparian zones even though they are surrounded by vast wetlands (Martini 2006). In the Ring of Fire region, the Boreal Shield ecozone consist of volcanic and intrusive bedrock (Metsaranta and Houle 2012) overlain with relatively thick layers of peat and glacial till (up to 76 m thick) with very little exposed bedrock (Dyer and Handley 2013). The Shield area has more topographic relief than the Hudson Plains but standing water is still a high percentage of land cover (Far North Advisory Panel 2010). The riparian zone of the Boreal Shield streams usually consists of quite dense cover of shrubs and trees (mainly *Picea mariana*) (Far North Advisory Panel 2010). The border between the two ecozones has been mapped using bedrock geology (Dyer and Handley 2013) but clear delineation of the transition between the two ecozones has been challenging due to extensive peat cover that may also affect hydrologic flows (Riley 2011). Macleod et al. (2016), for example, found very little difference in water chemistry in lakes within the transition zone between the two ecozones of the Ring of Fire region. Only when they included lakes further away from the transition zone could water chemistry analysis be used to clearly separate the two ecozones.

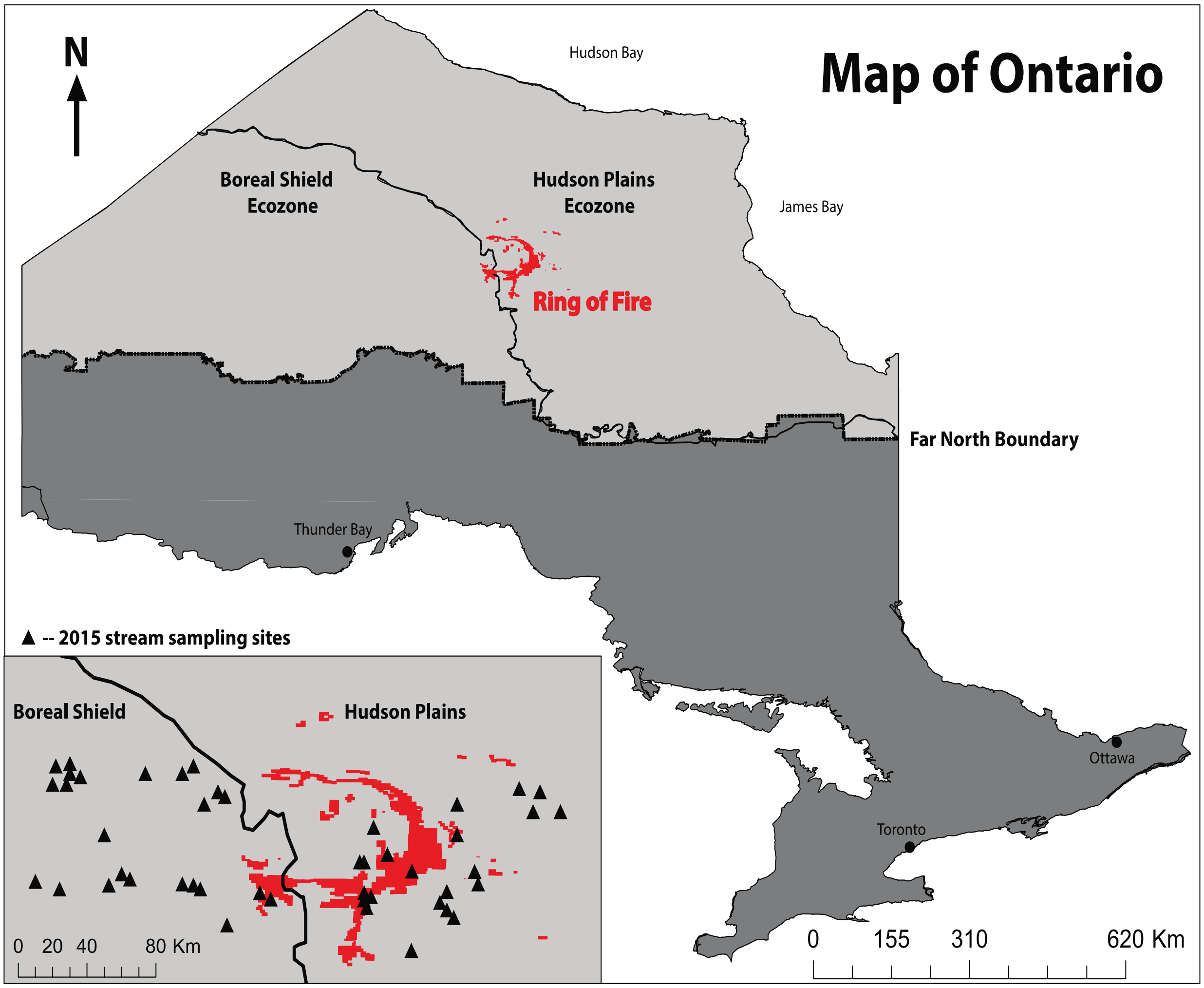


Figure 1. Potentially location of the Ring of Fire (with large deposits of platinum, nickel, copper and chromite) and 2015 stream sampling sites in relation to the ecozone transition area in the Far North of Ontario.

A stream biomonitoring and bioassessment program, using benthic macroinvertebrates (BMI) and other bioindicators is being created for the Ring of Fire region by the Ontario Ministry of Environment and Climate Change (J. Bailey, personal communication, 2015) to permit detection and monitoring of anthropogenic disturbances using the reference condition approach (Reynoldson et al. 1997). However, creating an effective design for a monitoring program in this new mining development region will be very challenging, not only because of the difficult access and the potential spatial habitat differences across the ecozone transitions, but because of possible increasing seasonal variability due to climate change.

Previous studies in other areas have demonstrated that BMI populations can exhibit wide seasonal variability (Hynes 1970, Boulton and Lake 1992) that can impact biomonitoring results (Linke et al. 1999). Common BMI community metrics, such as BMI richness and diversity measures, percent EPT and percent abundance of functional feeding groups have been shown to exhibit wide seasonal variability (Reece and Richardson 1998, Linke et al. 1999, Krolak and Korycinska 2007, Carlson et al. 2013, Johnson et al. 2012). Much of the seasonal variability has been attributed to taxa life history (Reece and Richardson 1998) associated with emergence and reproduction (Rosillon 1985) but BMI communities can also be heavily impacted by seasonal environmental changes in temperature, stream flow and water chemistry (Vannote and Sweeny 1980, Poff and Ward 1990) all of which may be impacted by climate change (Far North Advisory Panel 2010). How seasonal variation might change in a relatively pristine region across the habitat range observed in the ecozone transition area of the Ring of Fire region is largely unknown.

The objectives of my study were to assess seasonal variability of benthic macroinvertebrate communities and habitat characteristics in reference streams across the ecozone transition in the

Ring of Fire region. I hypothesized that the greatest amount of variability would be in the spring because of the timing of emergence and the effects of rapid habitat change (precipitation, water depth etc.). I also predicted that seasonal variability would differ between the two ecozones due to differences in topography and land cover. The wetlands and flat landscape of the Hudson Plains could buffer the benthic macroinvertebrate communities from flash changes in water levels leading to differences in seasonal variability between ecozones. This study was conducted in 2015: a year of highly variable stream flow conditions, and may prove instructive of the challenges faced when designing for monitoring under projected future climate conditions.

Methods

Study Sites

Forty-three stream sites were selected for this study using a random sampling method stratified by stream order to try to capture as broad a range as possible of stream habitat conditions in each ecozone. Selected stream sites had to be wadeable and shallow enough to be sampled safely using a hand-held kick net and each site had to have gravel to cobble substrate which is associated with a relatively narrow range of hydrological conditions (e.g. extreme high flow as well as silty/muddy quiescent sites were not sampled). These constraints on sampling sites were important for the sampling methods I used but there were very few streams in the Ring of Fire region that lacked potential sampling sites to fit these criteria. The Hudson Plains sites were selected as a subset of previously sampled sites (Novodvorsky and Bailey 2015) while the Boreal Shield sites were newly selected for this study. The 43 sampling sites were located across three secondary watersheds: the Winisk River, Attawapiskat River and Ekwan River (Natural Resources Canada 2003). Most sites were located on small tributaries flowing into large rivers such as the Muketei River and Attawapiskat River, while a few sites were on narrow sections of the larger rivers themselves.

In the final design fifteen sites were selected in the Hudson Plains ecozone while seventeen sites were in the Boreal Shield ecozone side (Figure 1). Each site was sampled three times in 2015: post-freshet (June 17th- 30th), mid-summer (July 24th –August 4th) and fall (September 24th- October 7th).

Benthic Macroinvertebrate Collection

I used the Canadian Aquatic Biomonitoring Network (CABIN) sampling protocol (Environment Canada 2012a) for my study. As per the protocol a three-minute traveling kick transect using a 400-μm kick net was used to collect the benthic invertebrates and samples were preserved in the field with 10% buffered formalin. In the laboratory, the samples were sieved (400-µm) and transferred to 70% ethanol before being sorted and identified following CABIN Laboratory Methods (Environment Canada 2012b). Each sample was subsampled using the Marchant Box Method (Marchant 1989) to a minimum of 300 individuals per sample. If more than 50% of the cells were sorted to reach the minimum required organisms, then the entire sample was processed. Samples were identified by a taxonomist certified by the Society of Freshwater Science Taxonomic Certification Program.

Environmental Variable Collection

Environmental variables measured at each site also followed CABIN stream sampling methods (Environment Canada 2012a). The mean stream flow at each site was calculated by averaging flow measurements across the BMI sampling site transect (6 equally spaced measurements if the stream was over 3 meters wide and 2 transects with 3 equally spaced measurements if the stream was under 3 meters wide). The stream macrophyte and canopy coverage were visually assessed (percent coverage estimated on a scale of 1-5) for the reach (6 times the width of the stream) by the sampling crew. The stream riparian zone (1-3 meters on either side of the stream) was assessed for types of vegetation present and the most prevalent vegetation. The stream bankfull width, wetted width, maximum water depth and altitude were also recorded at the BMI collection site for each stream.

Water chemistry measurements and sample collection occurred approximately 10-20 meters upstream from the BMI kick site following standard protocols (CCME 2011). A YSI probe was used to measure air temperature, surface water temperature, dissolved oxygen, specific conductance, and pH. Water samples were collected and stored in the dark on ice and sent to the Ontario Ministry of the Environment and Climate Change laboratory for analysis of metals, nutrients, major ions and other water quality variables.

Catchment area and average slope of each sampling site were determined using Digital Elevation Model raster layers (ASTER GDEM V2) and stream network layers (Geobase 2007) in the ArcHydro (10.2) tool extension for ArcGIS (10.3.1). The catchment for each site was intersected with Geogratis (Geogratis.gc.ca) shape files to describe bedrock geology and land cover characteristics.

Characterizing Sampling Year

Data from Environment Canada hydrometric stations were used to determine how stream flow in the 2015 sampling year compared to the long-term average (Environment Canada 2017). In each ecozone, the gauging station closest to sampling sites was chosen (Hudson Plains- Station#04FC001: 53°05'28" N 85°04'20" W, Boreal Shield- Station #04DA002: 52°57'35"N 87°41'22"W).

<u>Data Analyses</u>

Benthic Macroinvertebrates

Taxonomic identification was at the family rather than genus or species level, a resolution found suitable for statistical analyses in biomonitoring projects in the past (Bailey et al. 2001). Non-benthic taxa (terrestrial taxa, Daphniidae, and Hydridae) were removed from the dataset before statistical analysis. Only sites that were accessible to sample in all three seasons were included in final analyses which resulted in 15 sites in the Hudson Plains and 17 sites in the Boreal Shield.

Repeated measures ANOVAs (R Studio: ezANOVA function) assessed seasonal variability of family level BMIs. Calculated BMI community metrics included: Simpson's diversity, family richness, percent EPT (Ephemeroptera, Plecoptera and Trichoptera), percent Chironomidae, abundance and Hilsenhoff's Biotic Index (HBI) (Hilsenhoff 1987). Functional feeding groups (percent filterers, gatherers, predators, scrapers and shredders) were based on Merritt and Cummings (1996). The classification identified by Merrit and Cummins (1996) includes functional feeding behaviors of all possible taxa within a family and at varying life stages. BMIs that belonged to multiple functional feeding groups were included in calculations for all groups to which they belonged (standard method for functional feeding group calculations) (Dolédec et al. 2000, Gayraud et al. 2003). Repeated measures ANOVAs (R Studio: ezANOVA function) and non-metric multidimensional scaling (nMDS) ordination (R Studio: metaMDS function) using Bray-Curtis distances were used to compare community metrics among the three sampling periods (post-freshet, summer and fall) and interaction between seasons and ecozones.

Environmental Factors

A repeated measures ANOVA (R Studio: ezANOVA function) was performed on each habitat characteristic to assess possible drivers of seasonal change in BMI communities. Water chemistry was assessed with a correlation Principal Component Analysis (PCA) (R Studio: Princomp function). Values that were below the Laboratory Method Detection Limit (MDL) were included at half the MDL. Water chemistry variables that had half or more of their results below the MDL were not included in the PCA. Water chemistry data from sites that were sampled for BMIs in all three seasons were incorporated into the PCA (Hudson Plains: 15 sites and Boreal Shield: 17 sites). A distance based- redundancy analysis (db-RDA) (R Studio: capscale function) was used to characterize the drivers of seasonal variation in BMI communities. The drivers of the db-RDA included seasonally variable habitat characteristics (average depth (cm), macrophyte coverage (scale 0-5), canopy coverage (scale 0-5), average velocity (m/s), wetted width (m), maximum depth (cm) and water temperature (°C) and water chemistry PC1 and PC2 scores.

Ecozone Comparison

Ecozone characteristics were evaluated by assessing the environmental characteristics of the catchment for each site. The catchment characteristics were compared between ecozone with average percent of bedrock geology types, land cover characteristics and surficial geology types.

Results

Seasonal Variability: BMI Communities

High seasonal variability was observed at all levels of data organization, from the taxa level, to the metrics (including abundance), to the multivariate approaches. For example, out of the 182 families present, all eight of the most common taxa (i.e. those representing above) 5% of the relative abundance) showed significant seasonal variability (Baetidae, Ephemerellidae, Heptageniidae, Chironomidae, Simuliidae, Capniidae, Hydropsychidae and Sphaeriidae) and these taxa represented the majority (over 50%) of the total number of taxa (Table 1). Five (Baetidae, Ephemerellidae, Heptageniidae, Capniidae and Hydropsychidae) of these eight most common taxa that exhibited seasonal variability are a part of the commonly used percent EPT (Ephemeroptera, Plecoptera, Trichoptera) metric.

In addition, the community metrics that I proposed to use in subsequent monitoring programs showed significant seasonal variability (Table 2). Simpsons diversity and richness were much higher in the fall while HBI had the opposite trend. Percent EPT was lower in the summer, particularly in the Hudson Plains while percent Chironomids increased in the summer months. The percent gatherers increased over the three seasons while percent scrapers showed the opposite trend. Percent predators decreased in the fall. Seasonality of filterers and shredders were both impacted by ecozone. I also found that the post-freshet and summer sampling periods generated more similar metrics than statistical comparisons of either of these periods with results from the fall sampling. While seasonal variability in the metrics was evident for all the metrics, some ecozone level differences were also detected. For example, seasonality of filterers and shredders are both impacted by ecozone (Table 2).

Table 1. BMI (means and 95 % confidence intervals) of families that varied seasonally in relative abundance. Only families that represented of at least 5 % of the mean relative abundance are shown. The seasonal variability and ecozone interaction with seasonal variability were assessed with repeated measures ANOVAs (P<0.05 =*, P<0.01= **, P<0.001= ***). Hudson Plains (n=15 per season) and Boreal Shield (n=17 per season).

		Hudson Plains			Boreal Shield				
Order	**Family**	**Post-Freshet**	**Summer**	**Fall**	**Post-Freshest**	**Summer**	**Fall**	**Seasonal Variability**	**Season* Ecozone Interaction**
Ephemeroptera	**Baetidae**	28 +/-19.18	12 +/- 9.43	8 +/- 7.51	21 +/- 15.21	19 +/- 11.64	8 +/- 6.92	***	
	Ephemerellidae	1 +/- 1.34	2 +/- 2.44	8 +/- 11.66	3 +/- 3.34	2 +/- 1.14	17 +/- 12.48	***	
	Heptageniidae	1 +/- 1.81	2 +/- 1.69	3 +/- 3.61	1 +/- 1.05	2 +/- 1.38	5 +/- 4.22	***	
Diptera	**Chironomidae**	22 +/- 9.94	32 +/- 11.72	25 +/- 8.88	21 +/- 12.10	25 +/- 10.26	16 +/- 8.03	**	
	Simuliidae	15 +/- 10.36	12 +/- 13.68	0 +/- 0.19	29 +/- 30.44	14 +/- 17.40	16 +/- 22.55	***	
Plecoptera	**Capniidae**	0 +/- 0.43	0 +/- 0.18	7 +/- 9.68	0 +/- 0.08	0 +/- 0.00	0 +/- 0.24	**	**
Trichoptera	**Hydropsychidae**	0 +/- 0.39	5 +/- 5.79	6 +/- 7.05	1 +/- 0.87	3 +/- 2.95	5 +/- 4.35	***	
Veneroida	**Sphaeriidae**	9 +/- 14.21	10 +/- 8.94	6 +/- 6.36	7 +/- 9.49	15 +/- 14.69	8 +/- 9.18	***	

Table 2. Community metrics (means and 95% confidence intervals) compared among seasons and ecozone interaction with seasonal variability was assessed with repeated measures ANOVAs (P<0.05 =*, P<0.01= **, P<0.001= ***). Hudson Plains (n=15 per season) and Boreal Shield (n=17 per season).

	Hudson Plains			**Boreal Shield**			**Seasonal Changes**	**Season* Ecozone Interaction**
	Post-Freshet	**Summer**	**Fall**	**Post-Freshet**	**Summer**	**Fall**		
Simpsons Diversity	0.75 +/- 0.04	0.79 +/- 0.02	0.83 +/- 0.03	0.68 +/- 0.07	0.78 +/- 0.04	0.81 +/- 0.05	***	
Family Richness	20.06 +/- 2.18	24.25 +/- 1.77	25.06 +/- 2.98	20.72 +/- 2.08	22.94 +/- 1.84	24.67 +/- 1.71	***	
Abundance	2287 +/- 510.97	1497 +/- 522.13	942 +/- 259.47	3261 +/- 1197.76	1862 +/- 599.36	1226 +/- 369.64	***	
% EPT	33 +/- 8.00	19 +/- 4.00	4 +/- 7.00	31 +/- 6.00	27 +/- 4.00	34 +/- 6.00	***	
% Chironomids	23 +/- 5.00	31 +/- 5.00	24 +/- 4.00	21 +/- 5.00	24 +/- 4.00	16 +/- 3.00	**	
HBI	4.15 +/- 0.12	4.41 +/- 0.44	3.39 +/- 0.39	4.08 +/- 0.10	4.04 +/- 0.21	3.69 +/- 0.23	***	*
% Filterers	17 +/- 5.10	19 +/- 4.86	7 +/- 2.56	34 +/- 11.07	20 +/- 7.33	23 +/- 8.16	**	*
% Gatherers	47 +/- 8.17	54 +/- 7.00	58 +/- 6.83	40 +/- 7.45	49 +/- 6.48	53 +/- 7.18	***	
% Predators	43 +/- 5.54	53+/- 4.34	35 +/- 4.22	53+/- 8.57	45 +/- 6.22	44 +/- 6.65	***	
% Scrapers	53 +/- 7.76	37 +/- 6.77	22 +/- 5.11	56 +/- 8.38	41 +/- 5.45	33 +/- 7.63	***	
% Shredders	11+/- 3.04	9 +/- 1.85	23 +/- 5.76	3 +/- 0.95	5 +/- 1.81	6 +/- 1.35	***	***

Total abundance of macroinvertebrates captured in a standard three- minute kick survey also changed significantly across the seasons, decreasing by 35% in the Hudson Plains and 43% in the Boreal Shield from post-freshet to summer, and declining a further 24% in the Boreal Shield and 20% in the Boreal Shield by fall.

Multivariate approaches revealed similar patterns. BMI from sites sampled in the post-freshet and summer sampling periods were positioned in similar ordination space while the fall BMI communities were mostly separated from the other sampling periods (Figure 2). BMI had a higher chance of clustering with samples from the same season rather than samples from the same site. This seasonal variability of BMI communities was similar in both ecozones.

Seasonal Variability: Site Environmental Factors

Mean water temperature was similar in the post-freshet and summer, and decreased by over 7°C from the summer to fall in both ecozones (Table 3). The mean stream depth in the Hudson Plains increased during the summer months but stayed relatively consistent in the Boreal Shield. There was an interaction between ecozone and seasonality for the maximum depth, average depth, average velocity and water temperature suggesting that these site characteristics experience seasonality differently depending on the ecozone within which the stream site is located.

The PCA of water chemistry indicated a clear separation between the Boreal Shield and Hudson Plains streams (Figure 3). The first axis (explaining 43.30% of the variation) consisted mainly of variables associated with an increasing gradient of water hardness (e.g. pH, calcium, alkalinity, conductivity, potassium and magnesium) and a decreasing gradient of water colour (dissolved organic carbon (DOC), colour and iron). The factors that loaded heavily on the second

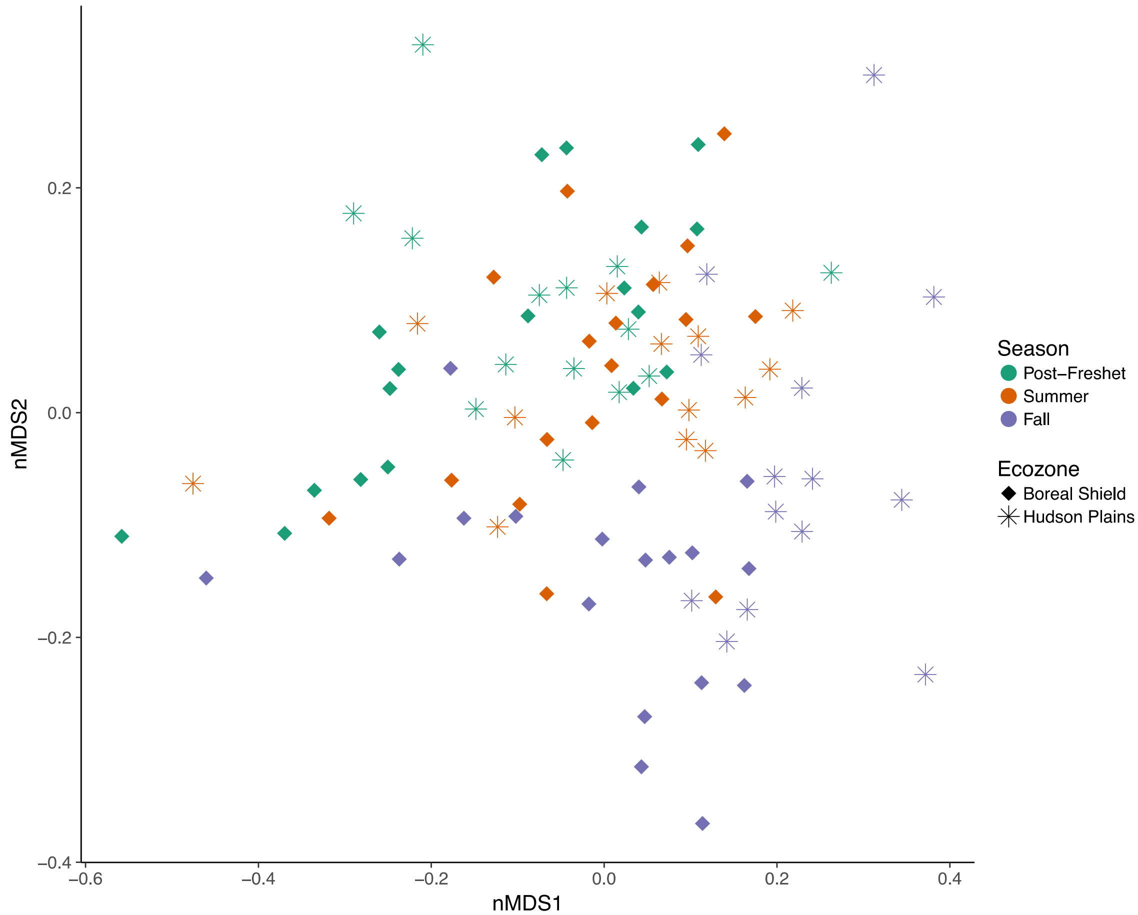


Figure 2. NMDS ordination plotting BMI communities collected from stream sites in the Hudson Plains (n= 15 per season) and Boreal Shield (n=17 per season). Sites were sampled three times: post-freshet, summer and fall.

Table 3. Site characteristics (means and 95% confidence intervals) for the Hudson Plains (n=15 per season) and Boreal Shield (n=17 per season). Repeated measures ANOVAs were used to compare variables over seasons and the interaction with ecozone (P<0.05 =*, P<0.01= **, P<0.001= ***).

	Hudson Plains			Boreal Shield			Seasonal Changes	Season* Ecozone Interaction
	Post-Freshet	Summer	Fall	Post-Freshet	Summer	Fall		
Max Depth (cm)	52.33 +/- 9.98	69.55 +/- 10.71	59.2 +/- 7.46	43.3 +/- 8.83	38.8 +/- 6.04	40.75 +/- 6.5		*
Average Depth (cm)	36.61 +/- 6.06	55.17 +/- 9.28	41.15 +/- 5.65	27.43 +/- 4.94	26 +/- 3.53	26.64 +/- 3.15	*	**
Max Velocity (m/s)	0.79 +/- 0.14	0.88 +/- 0.14	0.94 +/- 0.18	0.66 +/- 0.11	0.68 +/- 0.16	0.59 +/- 0.1		
Average Velocity (m/s)	0.42 +/- 0.08	0.56 +/- 0.1	0.56 +/- 0.12	0.34 +/- 0.07	0.35 +/- 0.07	0.34 +/- 0.07		*
Wetted Width (m)	9.82 +/- 3.17	8.05 +/- 2.73	9.63 +/- 3.13	15.47 +/- 5.09	15.17 +/- 5	15.51 +/- 5.06		
Water Temperature (°C)	16.18 +/- 0.94	19.1 +/- 1.09	12.08 +/- 0.56	19.16 +/- 1.22	16.23 +/- 0.64	8.86 +/- 0.51	***	***
Canopy Coverage (1-5 scale)	2	2	2	1	1	1		
Macrophyte Coverage (1-5 scale)	1	1	1	1	1	1		

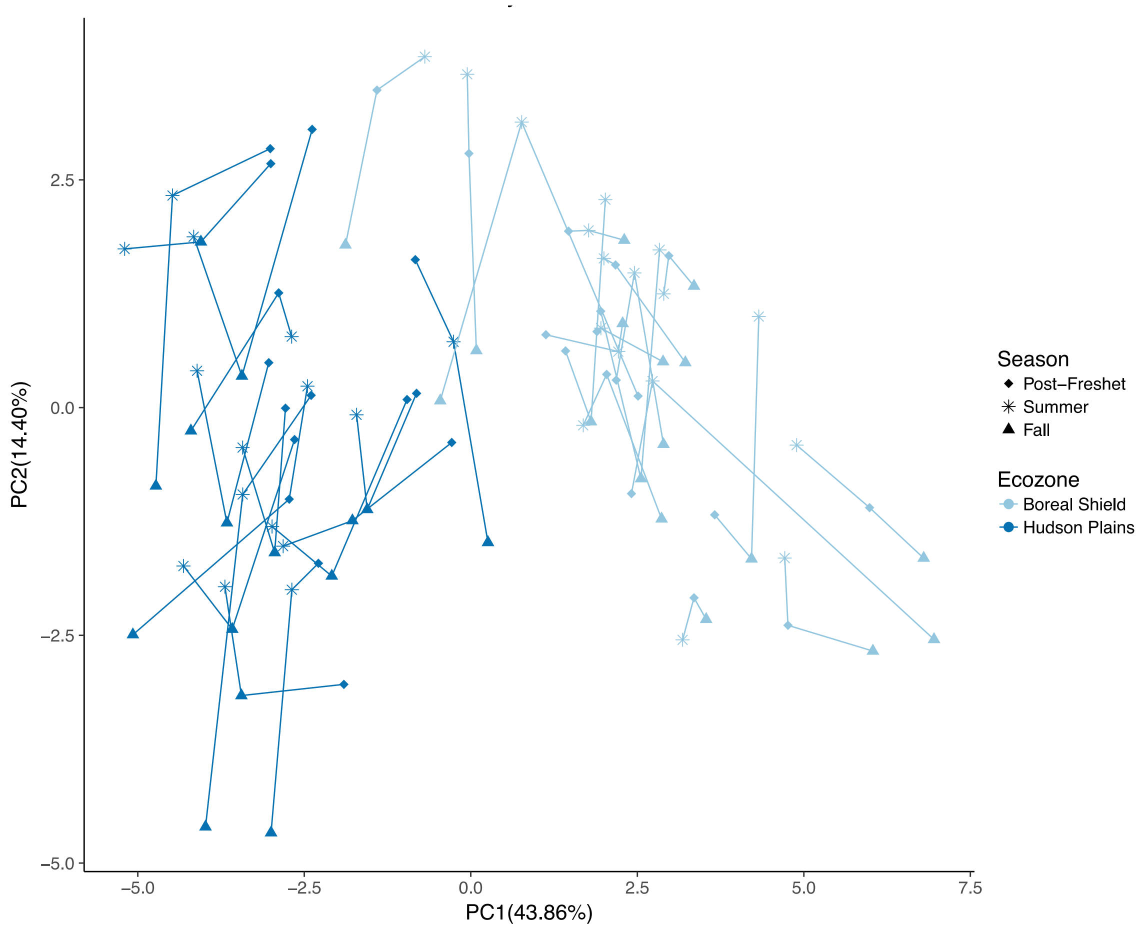


Figure 3. PCA correlation ordination of water chemistry from streams in the Hudson Plains (n=15 per season) and the Boreal Shield (n=17 per season). Each site was sampled post-freshet, summer and fall. The three sampling seasons of each site are connected.

Table 4. PC loadings for PC1 and PC2 axes (Figure 3) based on water chemistry variables from the Hudson Plains and Boreal Shield.

Water Chemistry Variables	**PC1**	**PC2**
Aluminum	-0.24	-0.21
Barium		-0.39
Calcium	0.29	-0.18
Iron	-0.24	-0.21
Alkalinity	0.30	-0.19
DOC	-0.28	
Colour	-0.30	-0.11
Cond.	0.28	-0.14
Dissolved Oxygen	0.13	-0.13
Hardness	0.28	-0.21
pH	0.24	0.24
Turbidity	-0.18	-0.18
Potassium	0.26	0.26
Magnesium	0.29	0.29
Manganese	-0.15	-0.15
Sodium		-0.20
NH4	0.17	-0.11
NO3	0.11	
TDN	0.17	
Phosphorous	-0.13	-0.33
Silicon		-0.23

axis, consisted of a range of variables (pH, K, Mg, Ba, Fe, hardness, P, Si and Sr) that explained 14.89% of the variation (Table 4). The visual ecozone separation on the PC1 axis was supported by the results of the repeated measures ANOVA on PC1 scores. The PC1 scores were significantly different ($P<0.05$) between ecozones and seasons, and had a significant interaction effect. The PC2 axis had an increasing gradient in pH and a decreasing gradient of hardness and nutrients. The repeated measures ANOVA determined that there were significant differences ($P<0.05$) in water chemistry among seasons, and between ecozones and there was a significant interaction effect.

Seasonal Variability: Environmental Drivers of BMI Variability

The benthic communities from each site were driven by some environmental characteristics (Figure 4). The post-freshet and summer sites grouped together while the fall sites BMI communities grouped together. The water temperature, canopy coverage and water chemistry PC2 scores drove the post-freshet and summer group while the velocity measurements impacted the BMI communities sampled in the fall. The BMI communities from both ecozones showed similar response to the environmental drivers.

Ecozone Comparison

The stream catchment characteristics were different between the Hudson Plains and the Boreal Shield (Table 5). The Hudson Plains sites had, on average, larger and flatter catchments and were at a lower altitude than the Boreal Shield sites. The dominant riparian vegetation cover was the similar in both ecozones. The site catchments in the Hudson Plains consisted of mainly sedimentary bedrock with minimal amounts of intrusive and volcanic bedrock (Table 6). The Boreal Shield mainly consisted of intrusive bedrock with some volcanic bedrock. The land cover of the catchments for the sites in the Boreal Shield was more variable than the sites from the

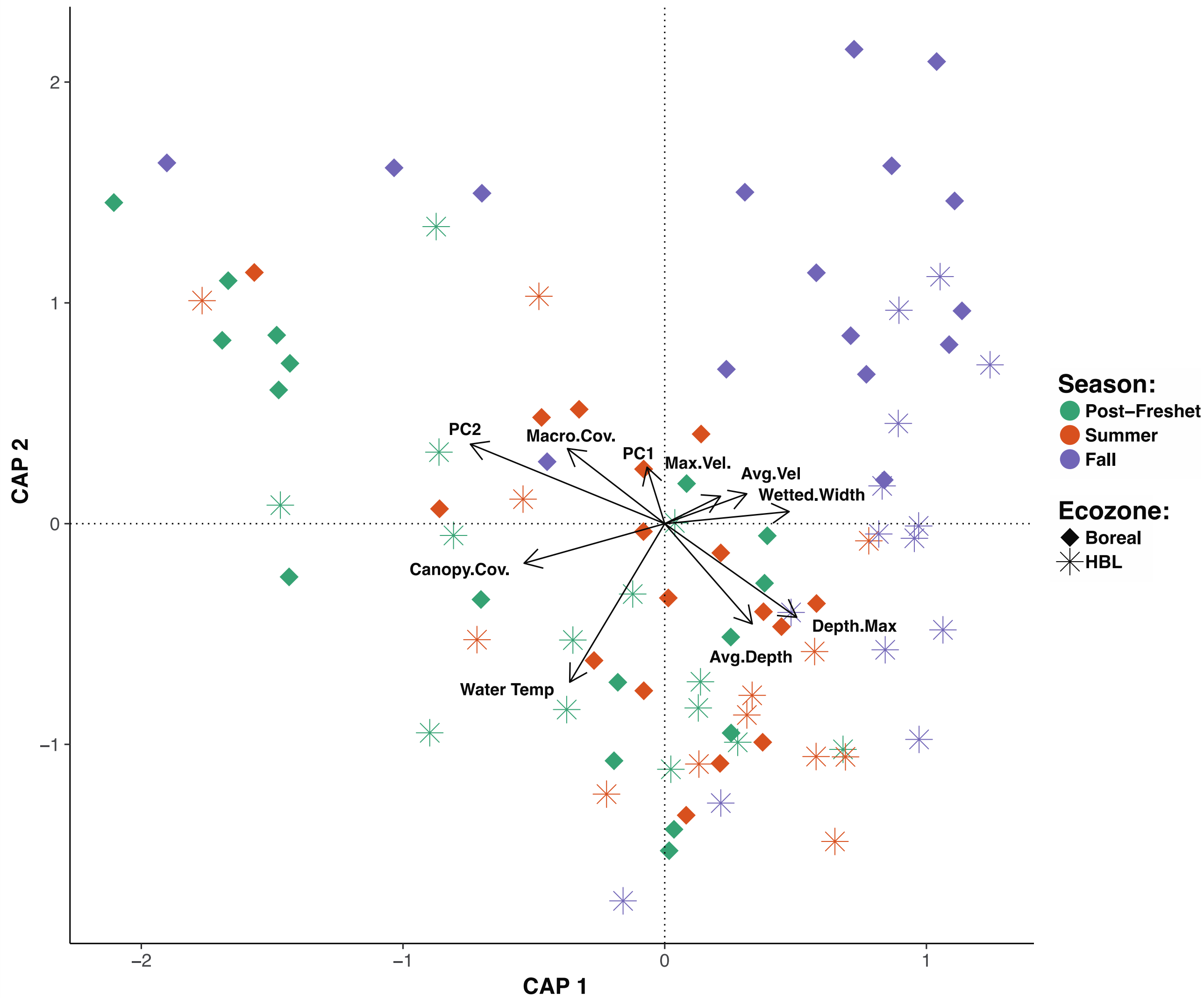


Figure 4. Distance based-RDA plotting BMI communities from the Hudson Plains (n= 15 per season) and Boreal Shield (n= 17 per season). Sites were sampled three times: post-freshet, summer and fall. The arrows represent drivers of the site groupings.

Table 5. Stream site characteristics compared between ecozones (Hudson Plains n=15 per season and Boreal Shield n=17 per season).

	Hudson Plains		Boreal Shield	
	Average	**Range**	**Average**	**Range**
Catchment Size (km^2)	125.70	1.05 - 479.99	4.00	1.22 - 7.71
Average Catchment Slope (%)	10.60	9.67 - 11.77	12.30	8.38 - 16.54
Stream Order	2	1 - 4	3	1-5
Altitude (feet)	490	252 - 662	657	400 - 761
Dominant Riparian Vegetation	Shrubs		Shrubs	
Riparian Vegetation (% of sites with this type of riparian vegetation present):				
Coniferous	92%		100%	
Deciduous	38%		38%	
Grass/Ferns	94%		98%	
Shrubs	97%		100%	

Table 6. Relative proportion of bedrock geology, surficial geology and land cover characteristics of stream catchments. Hudson Plains (n=15 per season) and Boreal Shield (n=17 per season).

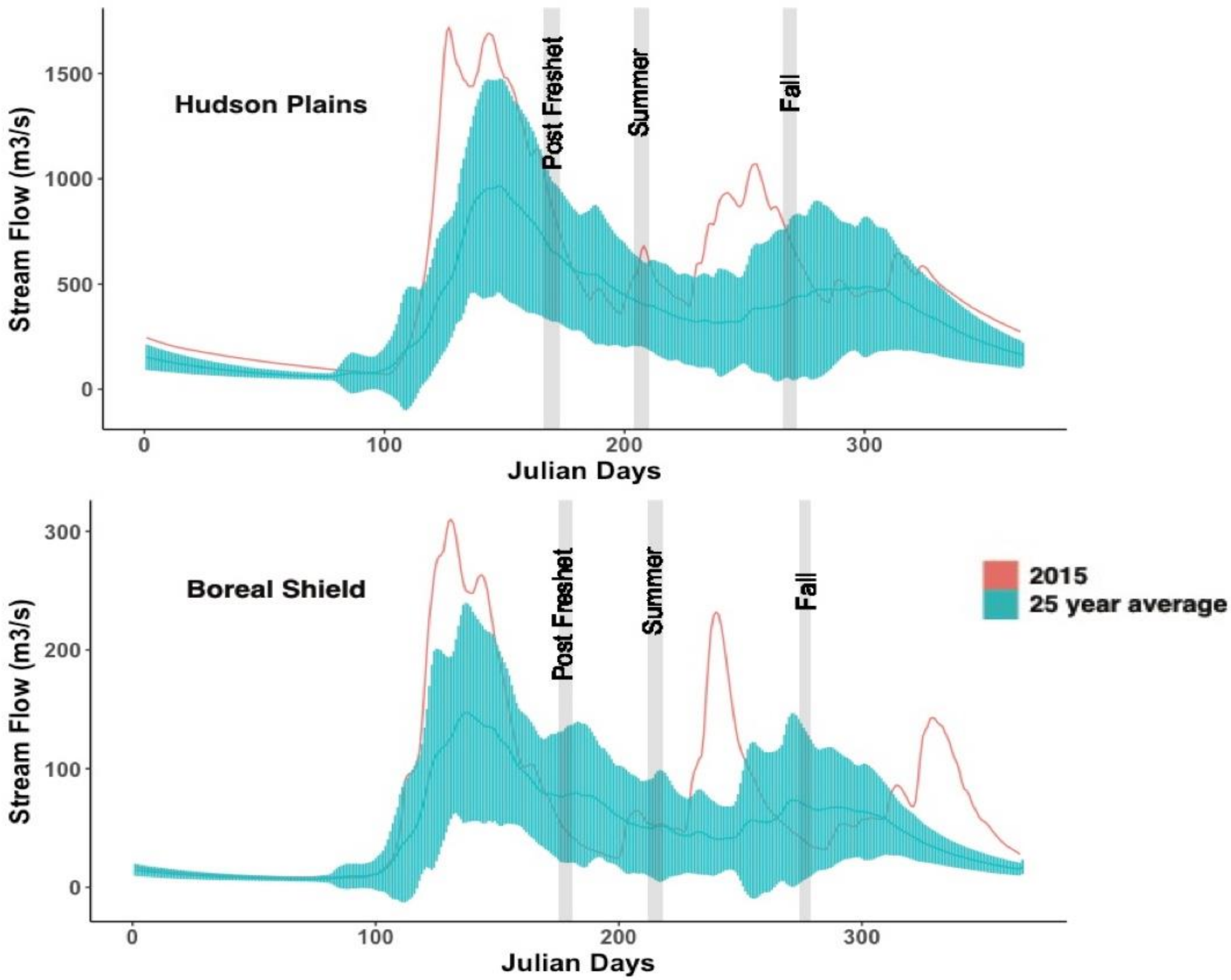
	Hudson Plains	Boreal Shield
Bedrock Geology		
Intrusive (%)	19.43 +/- 12.43	94.93 +/-3.90
Sedimentary (%)	78.18 +/-12.74	0.00 +/- 0.00
Volcanic (%)	2.39 +/- 2.72	5.07 +/-3.90
Surficial Geology		
Undifferentiated Bedrock (%)	0.00 +/- 0.00	0.05 +/- 0.08
Fine (%)	16.37 +/- 13.06	0.00 +/- 0.00
Organic (%)	13.71 +/-13.99	0.00 +/- 0.00
Till Blanket (%)	69.92 +/- 17.90	97.49 +/- 3.59
Till Veneer (%)	0.00 +/- 0.00	1.13 +/- 1.86
Land Cover		
BroadleafDense (%)	0.07 +/- 0.06	1.83 +/- 1.14
ConiferousDense (%)	8.61 +/- 3.57	16.10 +/- 4.02
Herb (%)	0.31 +/-0.32	16.90 +/-6.63
MixedwoodDense (%)	0.69 +/- 0.33	6.06 +/- 2.64
MixedwoodSparse (%)	2.81 +/- 0.98	19.83 +/- 4.97
ShrubLow (%)	0.00 +/- 0.00	8.15 +/- 2.95
Water (%)	7.49 +/- 2.10	15.63 +/- 3.17
WetlandShrub (%)	35.30 +/- 4.28	5.38 +/- 3.77
WetlandTreed (%)	44.56 +/-3.11	9.91 +/- 3.15

Hudson Plains (Table 6). The Hudson Plains watersheds mainly consisted of wetlands with trees and shrubs. The Boreal Shield had less wetlands with trees and shrubs. It mainly consisted of mixed wood dense and sparse forests, and coniferous dense forests. The Boreal Shield had a much higher percentage of water coverage within each site’s catchment than in the Hudson Plains.

Hydrology: 2015 Compared to Previous Years

The 2015 daily flow (m^3/s) was plotted in comparison to the 25-year average daily flow in a stream in the Hudson Plains and the Boreal Shield (Figure 5a and Figure 5b). The stream in the Hudson Plains and the stream in the Boreal Shield both had higher peak flow and more high flow events in 2015 than what was expected from the 25-year average. During the post-freshet sampling, streams from both ecozones had within average flow. However, during the summer sampling period, the stream in the Hudson Plains had increased flow while the stream in the Boreal Shield had flow that was within the range of standard deviation of the 25-year average flow. During the fall sampling, the stream in the Hudson Plains was initially higher than average flow and became within the 25-year average. During the fall sampling, the stream in the Boreal Shield was initially within the 25-year average than decreased to be below average.

Figure 5. Changes in daily stream flow (m^3/s) over a year from the closest gauging stations to sampling sites in a) Hudson Plains and b) Boreal Shield. The stream flow is compared between the 2015 sampling year and the 25-year average stream flow (1984- 2014, excluding 1994-1999 due to data availability). Standard deviation of 25-year average calculation included.



Discussion

Seasonal Variability: Benthic Macroinvertebrate Communities

As expected, the results indicated that BMI communities from the reference condition streams in the Ring of Fire region varied seasonally. Other studies have described seasonal changes in BMI communities to be related to taxa emergence patterns (Hynes 1970, Reece and Richardson 1998, Cowell et al. 2004). For example, a decline in BMIs abundance from spring to fall, as seen in my study, was also found by Hynes (1970) to be due to taxa emergence. The seasonally variable families (Table 1) have univoltine to multivoltine life cycles with dormant and active stages. These emergence characteristics could cause the relative abundance of family level BMIs to fluctuate significantly throughout the year (Merritt and Cummins 1996). For example, Capniidae mostly emerge in the spring and the winter months while Simulidae mostly emerge in the spring. It is not possible to quantify the precise emergence characteristics of BMIs when they are only identified at the family level. Lower level identification would be necessary to fully describe their seasonal life history characteristics. Percent Chironomidae tends to show opposite trends to percent EPT and increase in abundance during the warmer months (Johnson et al. 2012). I found that the percent EPT metric did indeed vary seasonally which corresponded with findings from other studies, many of which saw declines in the metric in the fall (Morais et al. 2004, Korlak and Korycinska 2007). HBI, another metric used to indicate the health of aquatic ecosystems, decreased over the three season in both ecozones. This pattern has been observed in other studies as well (Linke et al. 1999, Johnson et al. 2012). A decrease in HBI indicates an increase in sensitive taxa in the sample.

Stream BMIs tend to show a range of emergence patterns in areas with annual temperature and stream flow cycles like those of the Ring of Fire (Vannote and Sweeney 1980) and temperature and stream flow strongly effect emergence times of BMI taxa (Boulton and Lake 1992, Reece and Richardson 1998). Reece and Richardson (1998), found that although emergence caused abundance declines throughout the seasons, environmental variables such as flow regime and water temperatures, were strongly correlated with timing of the emergence. Seasonal patterns of non-emergent taxa can also be directly related to environmental characteristics, for example, the relative abundance of the fingernail clam (Sphaeriidae) has been shown to be related to stream flow fluctuations (not temperature) because extreme flow events can severely alter the stream bottom conditions (Hornbach and Wissing 1982). In my study the large episodic flow events which I experienced when sampling, particularly in the Hudson Plains sites between the summer and fall sampling periods, could have been responsible for some of the reduced relative abundance detected.

Seasonal variation in functional feeding groups has been associated with changes in site environmental characteristics that shift food sources available for BMI communities (Cummins and Klug 1979). For example, fine particulate organic matter (FPOM) provides an important food source for filterers (Carlson et al. 2013) and its availability tends to increase in warmer water temperature (Šporka et al. 2006). Coarse particulate organic matter (CPOM) plays a similar role for gatherers (Carlson et al. 2013) and their abundances increase in the fall when the CPOM availability tends to increase (Šporka et al. 2006). These general trends were detected in the functional feeding group responses assessed in my study. Periphyton is a primary food source for scrapers and can be impacted by seasonal changes in temperature, flow and light attenuation (Šporka et al. 2006). I found that the average percent of scrapers decreased across sampling seasons which appears to indicate a reduction in food (periphyton) availability over the three seasons. Periphyton abundance in streams would need to be measured to properly measure the association of scrapers with periphyton availability in the Ring of Fire streams.

The post-freshet and summer BMI communities were more similar to each other than communities from the fall sampling period. As discussed above many BMIs emerge during the spring season following temperature change and increased stream flow (Hynes 1970, Reece and Richardson 1998). In my study, the post-freshet and summer sampling period water temperature averages were similar and had already increased to above 20°C, indicating that the change in temperature that can trigger emergence in BMIs likely occurred before the first post-freshet sampling period. In addition to the water temperatures the stream flow estimates for each ecozone (Figure 5) suggested that the peak flow that may have also triggered emergence, had already occurred prior to sampling.

Northern Ontario has a relatively cold climate and short ice-free season that compresses the available open water sampling window, making it more difficult to schedule sample collections. Intense spring freshets also render the streams inaccessible for sampling during this earliest period of the year in the Ring of Fire region. My study also encountered highly variable stream flow conditions within the 2015 study year, which illustrates some of the challenges faced when designing monitoring programs under projected changing climate conditions.

Seasonal Variability: Water Chemistry

Stream source waters likely explain seasonal variability of water chemistry parameters. Orlova and Branfireun (2014), conducted a study of stream water inputs for a stream in the James Bay Lowlands (study site approximately 150 kms east of the Ring of Fire), which indicated that streams are mainly fed by runoff from peatlands (53-67% depending on the catchment area) followed by bedrock streamflow (20-40% depending on catchment area). They found that during the spring, snowmelt is the highest contributor to stream flow, whereas in summer low flow conditions, precipitation is the highest contributor. During wet periods, there is increased contribution of water to streams by peatlands due to higher water tables and greater hydrologic connectivity.

Seasonal Variability: Impact of Ecozone

Sites from the two ecozones had differing catchment characteristics, yet ecozone location had little influence on the seasonal variability of BMI communities. This could in part be due to the need to select similar immediate stream site conditions (stream flow, riffle habitat, hard bottom and wadeable depth), with the result that associated riparian vegetation at the sites was also quite similar in both ecozones. The standard stream conditions were a requirement of performing the CABIN sampling procedures. This selection causes the within stream site characteristics to be very similar between ecozones. The streams in the Hudson Plains also have a natural vegetation buffering zone around them that is forested and is very similar to the Boreal Shield riparian zone even though the larger watershed characteristics may be quite different (Martini 2006). Multiple studies have indicated that BMI communities are closely linked to reach and riparian characteristics instead of larger catchment characteristics (Richards et al. 1995, Rios and Bailey 2004). If the communities have same riparian zone leading to similar BMI communities, they could have similar emergence characteristics and response to seasonal environmental changes. This could also suggest that flow patterns and water temperature are the main seasonally variable habitat characteristics driving the BMI communities. Another possible reason for the lack of ecozone differences is that in spite of the bedrock geology differences there is a thick layer of glacial till covering much of the bedrock in both ecozones in the Ring of Fire region (Dyer and Handley 2013).

I found that the stream water chemistry did differ between the Hudson Plains and the Boreal Shield sampling sites. In contrast, Macleod et al. (2016), found that lake water chemistry was not different between ecozones in the Ring of Fire region and that is was necessary to look at lakes farther away from the transition zone to see differences. Lakes spread across the far north of Ontario showed high ionic strength (Ca, Mg, pH and conductivity) in the Boreal Shield, and increased in acidity, DOC and colour in the Hudson Plains. This is similar to the water chemistry conditions I found in streams in the Ring of Fire region. The water that is feeding the lake systems could be flowing over land cover and/or bedrock geology which differs between the two ecozones and could lead to the observed differences in water chemistry. For example, a study by Dillon and Molot (1997) showed that the amount of peatland in stream catchments is associated with increases in DOC and iron in stream systems.

Comparing to Previous Years

In addition to seasonal variability, temporal variations of BMI communities can occur inter-annually. Inter-annual variability could impact biomonitoring results (Munne and Prat 2011). This variability has been attributed to natural fluctuation in populations, variability in recruitment and changes in habitat conditions (Bady et al. 2004). Stream flow changes can also influence benthic macroinvertebrate communities (Lamouroux et al. 2004). Mean stream flow from the 2015 study year was compared to the 25-year average flow to provide insight into annual variability of BMIs. In comparison to a 25-year average flow, the 2015 sampling year was a much wetter year with higher peak flow events. The spring freshet occurred earlier in 2015 compared to the 25-year average. There was a summer storm event increasing precipitation inputs into streams in the Hudson Plains which was reflected in the summer Hudson Plains stream site's water velocity variables. The characteristics of the 2015 flow regime are similar to what is expected for the region under climate change conditions in the climate change models discussed by the Far North Advisory Panel (2010) and therefore the results of this study might not be indicative of the long-term average hydrological conditions in the region, but may be more relevant to future conditions under a warmer climate with earlier spring freshet, drier peatlands and higher peak flow events.

Two of the main drivers associated with seasonal variability of BMI communities, flow and temperature, are predicted to be affected by climate changes. Climate models predict a rise in temperature and precipitation with increased evapotranspiration leading to a drier environment in this region. Reduction of water availability in peatlands will reduce the amount of water feeding the streams from peatlands leading to increased relative ground water contributions (Orlova and Branfireun 2014). These changes in stream flow regimes and temperature could influence emergence time of BMIs by causing spring emergence triggered by increased temperatures or the spring freshet to occur earlier. Increased large precipitation events could influence certain taxa (for example Sphaeriidae which is influenced by stream flow fluctuations). There could also be a community shift to taxa that are usually found in warmer shallow waters.

Implication of Seasonal Changes to Biomonitoring

The far north of Ontario is a sensitive ecosystem that is facing the potential for the Ring of Fire mining development while experiencing climate change. Environmental monitoring provides baseline conditions from which we can measure changes, detect adverse effects and inform policies and programs to mitigate impacts. I recommend that benthic macroinvertebrates communities be integrated into environmental regulations as indicators of aquatic ecosystem health. Due to the seasonal variability of benthic macroinvertebrate communities I recommend that sites are sampled in the same season each year. The ordination results indicate that there was less variability between the post-freshet sampling and the summer sampling seasons, compared to the fall season, therefore focusing sampling in the post-freshet and summer seasons will minimize the potential influence of seasonal variability. The findings of this study can inform the design of research and monitoring programs in the region by minimizing the potential influence of seasonal variability on biomonitoring programs. This is important, as it allows comparable data to be collected over time to assess trends and changes without the confounding influences of season.

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Appendices

Table 7. Water chemistry parameters sampled using a YSI probe(*) and laboratory analysis.

Air Temperature*	Chloride	Mercury	Strontium
Alkalinity	Chromium	Molybdenum	Sulphate
Aluminum	Cobalt	Nickel	Thallium
Ammonium	Colour	Nitrate	Titanium
Antimony	Conductivity*	Nitrate+Nitrite	Total Nitrogen
Arsenic	Copper	Nitrite	Total Phosphorous
Barium	DOC	pH	Turbidity*
Beryllium	Hardness	Potassium	Uranium
Boron	Iron	Selenium	Vanadium
Bottom Dissolved Oxygen*	Lead	Silicon	Water Temperature*
Cadmium	Magnesium	Silver	Zinc
Calcium	Manganese	Sodium	

Table 8. Average and 95% confidence intervals of water chemistry parameters between ecozones and among seasons.

	Hudson Plains						Boreal Shield					
	Spring		Summer		Fall		Spring		Summer		Fall	
Al (mg/L)	0.06	+/- 0.01	0.06	+/- 0.01	0.05	+/- 0.01	0.01	+/- 0.00	0.01	+/- 0	0.01	+/- 0.00
Ba (mg/L)	0	+/- 0.00	0.01	+/- 0.00	0.01	+/- 0	0	+/- 0.00	0	+/- 0	0	+/- 0
Ca (mg/L)	10.16	+/- 0.88	11.22	+/- 0.95	11.36	+/- 1.19	15.22	+/- 1.37	16.94	+/- 1.21	17.52	+/- 1.46
Fe (mg/L)	0.43	+/- 0.05	0.53	+/- 0.07	1.01	+/- 0.15	0.1	+/- 0.03	0.04	+/- 0.00	0.09	+/- 0.04
Alkalinity (mg/L)	29.47	+/- 3.29	30.74	+/- 3.48	32.98	+/- 4.20	49.45	+/- 5.12	51.76	+/- 4.43	58.42	+/- 5.88
DOC (mg/L)	15.77	+/- 0.81	20.28	+/- 1.16	19.26	+/- 1.04	11.69	+/- 0.49	13.17	+/- 0.86	13.26	+/- 0.97
Colour	140.01	+/- 12.70	182.01	+/- 18.90	191.55	+/- 19.78	57.76	+/- 6.45	58.13	+/- 10.18	62.95	+/- 10.54
Cond. (µS/cm)	58.04	+/- 5.86	54.97	+/- 5.36	48.61	+/- 5.85	91.68	+/- 9.09	84.68	+/- 7.01	75.07	+/- 7.83
DO (mg/L)	8.52	+/- 0.31	7.14	+/- 0.35	9.08	+/- 0.32	8.3	+/- 0.32	8.6	+/- 0.39	10.69	+/- 0.29
Hardness (mg/L)	32.19	+/- 2.59	35.12	+/- 2.91	38.25	+/- 3.53	49.05	+/- 5.21	51	+/- 3.77	57	+/- 5.81
pH	7.52	+/- 0.11	6.9	+/- 0.12	7.13	+/- 0.11	8.03	+/- 0.17	7.53	+/- 0.16	7.71	+/- 0.14
Air Temp. (C)	16.52	+/- 0.99	22.16	+/- 1.27	14.39	+/- 1.72	20.09	+/- 2.07	14.61	+/- 0.76	11.02	+/- 1.83
Water Temp. (C)	16.23	+/- 0.89	18.96	+/- 1.05	11.99	+/- 0.54	19.11	+/- 1.23	16.29	+/- 0.67	8.84	+/- 0.53
Turbidity (NTU)	2.47	+/- 0.94	2.29	+/- 0.48	3.54	+/- 1.45	0.74	+/- 0.14	0.57	+/- 0.15	0.65	+/- 0.15
K (mg/L)	0.09	+/- 0.02	0.08	+/- 0.02	0.18	+/- 0.02	0.35	+/- 0.07	0.31	+/- 0.07	0.33	+/- 0.07
Mg (mg/L)	1.62	+/- 0.17	1.74	+/- 0.17	1.8	+/- 0.21	2.74	+/- 0.29	3.02	+/- 0.29	3.1	+/- 0.32
Mn (mg/L)	0.02	+/- 0.00	0.03	+/- 0.01	0.06	+/- 0.02	0.02	+/- 0.01	0.01	+/- 0.00	0.01	+/- 0.00
Na (mg/L)	0.81	+/- 0.24	0.68	+/- 0.19	0.66	+/- 0.12	0.5	+/- 0.03	0.52	+/- 0.03	0.55	+/- 0.03
NH4 (mg/L)	0.02	+/- 0.00	0.02	+/- 0.00	0.02	+/- 0.00	0.04	+/- 0.01	0.03	+/- 0.00	0.06	+/- 0.02
NO3 (mg/L)	0.02	+/- 0.00	0.02	+/- 0.00	0.02	+/- 0.00	0.02	+/- 0.00	0.02	+/- 0.00	0.05	+/- 0.02
Total N (mg/L)	0.42	+/- 0.02	0.39	+/- 0.02	0.39	+/- 0.05	0.5	+/- 0.03	0.48	+/- 0.02	0.48	+/- 0.03
Total P (mg/L)	0.01	+/- 0.00	0.01	+/- 0.00	0.01	+/- 0.00	0.01	+/- 0.00	0.01	+/- 0.00	0.01	+/- 0.00
Si (mg/L)	0.6	+/- 0.10	1.11	+/- 0.12	1.38	+/- 0.11	0.56	+/- 0.09	1.1	+/- 0.11	1.13	+/- 0.12
Sr (mg/L)	0.02	+/- 0.00	0.02	+/- 0.00	0.02	+/- 0.00	0.02	+/- 0.00	0.01	+/- 0.00	0.02	+/- 0.00

Table 9. BMI family averages and 95% confidence intervals between ecozones and among seasons.

	Hudson Plains			**Boreal Shield**		
	Spring	**Summer**	**Fall**	**Spring**	**Summer**	**Fall**
Aeshnidae	0.11+/-0.23	0.2+/-0.49	0.06+/-0.13	0.04+/-0.10	0.02+/-0.07	0.05+/-0.11
Ameletidae	0+/-0	0+/-0	0+/-0	0+/-0	0+/-0	0+/-0
Ancylidae	0+/-0	0.64+/-1.31	0.19+/-0.51	0.04+/-0.15	0.09+/-0.21	0.04+/-0.10
Aphididae	0+/-0	0+/-0	0.19+/-0.72	0+/-0	0+/-0	0+/-0
Arrenuridae	0+/-0	0+/-0	0+/-0	0.02+/-0.08	0+/-0	0+/-0
Athericidae	0+/-0	0.12+/-0.26	0.16+/-0.38	0+/-0	0.04+/-0.11	0.05+/-0.22
Aturidae	0+/-0	0.03+/-0.13	0.05+/-0.14	0.02+/-0.08	0.02+/-0.08	0.03+/-0.09
Baetidae	27.79+/-19.18	11.91+/-9.43	7.6+/-7.51	20.59+/-15.21	19+/-11.64	8.22+/-6.92
Brachycentridae	0+/-0	0+/-0	0.05+/-0.18	0.04+/-0.10	0.01+/-0.05	0.26+/-1.07
Caenidae	0.11+/-0.28	0.12+/-0.26	0.3+/-0.78	0.92+/-1.46	0.28+/-0.34	0.16+/-0.47
Cambaridae	0+/-0	0+/-0	0+/-0	0.03+/-0.11	0+/-0	0+/-0
Capniidae	0.11+/-0.43	0.09+/-0.18	7.34+/-9.68	0.02+/-0.08	0+/-0	0.13+/-0.24
Ceratopogonidae	0.29+/-0.44	0.11+/-0.20	0.41+/-0.98	0.23+/-0.31	0.08+/-0.16	0.12+/-0.24
Chironomidae	22.35+/-9.94	31.59+/-11.72	25.1+/-8.88	21.25+/-12.10	24.51+/-10.26	16.31+/-8.03
Chloroperlidae	0.04+/-0.10	0+/-0	0.06+/-0.18	0+/-0	0+/-0	0+/-0
Chrysomelidae	0.02+/-0.07	0+/-0	0+/-0	0+/-0	0+/-0	0+/-0
Coenagrionidae	0+/-0	0+/-0	0+/-0	0.02+/-0.08	0.02+/-0.07	0+/-0
Cordulegastridae	0.02+/-0.07	0+/-0	0.07+/-0.25	0+/-0	0+/-0	0+/-0
Corduliidae	0.02+/-0.07	0+/-0	0+/-0	0.07+/-0.13	0.07+/-0.20	0.02+/-0.07
Corixidae	0+/-0	0+/-0	0.15+/-0.27	0.22+/-0.87	0+/-0	0.04+/-0.09
Dixidae	0+/-0	0+/-0	0+/-0	0+/-0	0.01+/-0.06	0+/-0
Dolichopodidae	0+/-0	0.03+/-0.10	0+/-0	0+/-0	0+/-0	0+/-0
Dytiscidae	0.1+/-0.23	0.1+/-0.25	0.03+/-0.07	0.02+/-0.06	0+/-0	0+/-0

Elmidae	6.82+/-6.3	5.54+/-4.39	7.68+/-8.60	1.16+/-1.66	1.48+/-2.12	1.97+/-2.24
Empididae	1.1+/-1.21	0.25+/-0.38	1.39+/-1.33	0.6+/-0.71	0.7+/-0.46	1.54+/-1.07
Enchytraeidae	0.69+/-0.72	0.88+/-0.91	0.76+/-1.18	0.24+/-0.48	0.36+/-1.14	0.32+/-1.06
Ephemerellidae	1.2+/-1.34	1.7+/-2.43	8.07+/-11.66	2.52+/-3.34	1.66+/-1.36	16.8+/-12.48
Ephemeridae	0.31+/-0.50	0.32+/-0.60	0.11+/-0.14	0+/-0	0+/-0	0+/-0
Erpobdellidae	0.02+/-0.09	0.04+/-0.11	0.02+/-0.08	0+/-0	0.02+/-0.08	0.02+/-0.07
Gammaridae	0.08+/-0.25	0.05+/-0.17	0+/-0	0+/-0	0+/-0	0.02+/-0.07
Glossiphoniidae	0.02+/-0.07	0.14+/-0.37	0.04+/-0.17	0+/-0	0.02+/-0.08	0+/-0
Glossosomatidae	0.52+/-0.94	3.99+/-9.55	1.62+/-3.04	0.08+/-0.17	0.08+/-0.23	0.24+/-0.51
Gomphidae	0.05+/-0.17	0.13+/-0.36	0.13+/-0.25	0.62+/-0.94	0.75+/-1.01	0.9+/-1.53
Gyrinidae	0+/-0	0+/-0	0.02+/-0.09	0+/-0	0+/-0	0+/-0
Haemopidae	0+/-0	0+/-0	0+/-0	0+/-0	0+/-0	0.02+/-0.06
Helicopsychidae	0+/-0	0+/-0	0.01+/-0.04	0.22+/-0.55	0.85+/-1.55	0.02+/-0.10
Heptageniidae	1.36+/-1.81	1.86+/-1.69	3.14+/-3.61	1.09+/-1.05	1.71+/-1.38	4.78+/-4.22
Hyalellidae	0.02+/-0.08	0.19+/-0.42	0.06+/-0.12	0.26+/-0.38	0.92+/-2.21	0.55+/-1.53
Hydrobiidae	0.09+/-0.19	0+/-0	0.05+/-0.18	0.06+/-0.12	0.18+/-0.73	0.03+/-0.09
Hydrochidae	0+/-0	0.02+/-0.08	0+/-0	0+/-0	0+/-0	0+/-0
Hydrodromidae	0+/-0	0+/-0	0+/-0	0.03+/-0.10	0+/-0	0+/-0
Hydropsychidae	0.22+/-0.39	4.97+/-5.79	6.15+/-7.05	0.77+/-0.87	3.28+/-2.95	5.44+/-4.35
Hydroptilidae	2.95+/-3.41	0.88+/-1.51	0.94+/-2.32	1.22+/-1.31	1.71+/-2.86	1.26+/-1.65
Hydryphantidae	0.02+/-0.08	0+/-0	0.01+/-0.04	0.02+/-0.07	0+/-0	0+/-0
Hygrobatidae	0.47+/-0.94	0.76+/-0.53	0.19+/-0.33	0.52+/-0.77	0.95+/-1.24	0.42+/-0.78
Isonychiidae	0+/-0	0.03+/-0.08	0.1+/-0.24	0.15+/-0.30	0.17+/-0.34	0.72+/-1.34
Lebertiidae	0.15+/-0.27	0.29+/-0.40	0.38+/-0.89	0.02+/-0.08	0.14+/-0.35	0.25+/-0.39
Lepidostomatidae	0.38+/-0.62	0.53+/-0.63	1.78+/-2.41	0.19+/-0.29	1.53+/-4.17	0.97+/-0.70
Leptoceridae	0.14+/-0.21	0.38+/-0.61	0.16+/-0.33	0.67+/-0.76	1.19+/-1.26	0.65+/-0.68
Leptohyphidae	0+/-0	0.21+/-0.64	0+/-0	4.71+/-6.20	0.46+/-1.17	0+/-0
Leptophlebiidae	0.67+/-0.92	1.86+/-2.50	4.86+/-6.29	0.27+/-0.55	1.39+/-1.38	3.12+/-3.13

Leuctridae	1.67+/-1.93	0.77+/-1.38	1.92+/-2.70	0.18+/-0.55	0.02+/-0.08	0.26+/-0.97
Libellulidae	0+/-0	0+/-0	0.02+/-0.08	0+/-0	0+/-0	0+/-0
Limnephilidae	0.17+/-0.45	0.26+/-0.56	0.73+/-1.41	0.3+/-0.59	0.17+/-0.28	0.5+/-0.46
Limnesiidae	0+/-0	0.05+/-0.12	0+/-0	0+/-0	0+/-0	0+/-0
Lumbriculidae	0.16+/-0.31	0.15+/-0.42	0.02+/-0.08	0.12+/-0.18	0.07+/-0.18	0.12+/-0.35
Lymnaeidae	0.02+/-0.08	0.31+/-1.148	0.02+/-0.06	0.07+/-0.18	0.11+/-0.30	0.09+/-0.29
Metretopodidae	0+/-0	0+/-0	0.01+/-0.04	0+/-0	0+/-0	0+/-0
Mideopsidae	0.04+/-0.11	0.02+/-0.06	0+/-0	0.01+/-0.06	0.04+/-0.10	0+/-0
Naididae	0.35+/-0.70	0.82+/-0.90	0.9+/-1.62	0.29+/-0.41	0.39+/-0.41	1.99+/-4.52
Nemouridae	2.43+/-6.24	0.88+/-1.97	4.95+/-13.86	0.56+/-1.28	0.22+/-0.52	0+/-0
Noctuidae	0+/-0	0.02+/-0.08	0+/-0	0+/-0	0+/-0	0+/-0
Odontoceridae	0+/-0	0.31+/-0.46	0.04+/-0.13	0.03+/-0.08	0.07+/-0.13	0.07+/-0.17
Perlidae	0.28+/-0.43	0.27+/-0.37	0.34+/-0.44	0.41+/-0.68	0.18+/-0.33	0.49+/-0.59
Perlodidae	0.29+/-0.67	0.12+/-0.33	1.72+/-2.77	0.05+/-0.16	0.31+/-0.59	2.13+/-1.31
Philopotamidae	0.48+/-1.24	1.42+/-3.20	0.82+/-1.34	0.18+/-0.30	1.93+/-3.56	2+/-3.76
Phryganeidae	0.02+/-0.07	0.02+/-0.09	0.09+/-0.34	0+/-0	0.15+/-0.22	0+/-0
Physidae	0.04+/-0.14	0.19+/-0.51	0.05+/-0.10	0.66+/-1.43	0.08+/-0.16	0+/-0
Pisidiidae	9.37+/-14.21	10.13+/-8.94	5.77+/-6.36	7.17+/-9.49	15.46+/-14.69	8.47+/-9.18
Planorbidae	0.04+/-0.10	0.27+/-0.59	0.02+/-0.08	1.04+/-1.93	2.42+/-3.40	0.88+/-1.40
Polycentropodid ae	0.05+/-0.12	0.13+/-0.24	0.07+/-0.18	0+/-0	0.27+/-0.38	0.28+/-0.50
Psychomyiidae	0.09+/-0.19	0.02+/-0.09	0.24+/-0.45	0+/-0	0+/-0	0.06+/-0.12
Pteronarcyidae	0.02+/-0.08	0+/-0	0+/-0	0+/-0	0.05+/-0.21	0.02+/-0.07
Rhyacophilidae	0+/-0	0.32+/-0.80	0.19+/-0.45	0.06+/-0.20	0.05+/-0.16	0.2+/-0.46
Scirtidae	0+/-0	0+/-0	0.02+/-0.06	0+/-0	0+/-0	0+/-0
Sialidae	0+/-0	0+/-0	0.02+/-0.08	0+/-0	0+/-0	0+/-0
Simuliidae	14.7+/-10.36	11.75+/-13.68	0.14+/-0.19	29.41+/-30.44	13.54+/-17.40	15.71+/-22.55
Sperchontidae	0.7+/-0.79	0.69+/-0.72	0.85+/-1.09	0.25+/-0.39	0.28+/-0.33	0.36+/-0.55
Staphylinidae	0+/-0	0.02+/-0.07	0+/-0	0+/-0	0+/-0	0+/-0

Tabanidae	0+/-0	0.11+/-0.34	0+/-0	0+/-0	0+/-0	0+/-0
Taeniopterygidae	0.15+/-0.26	0+/-0	0.26+/-0.34	0+/-0	0+/-0	0.42+/-0.53
Tipulidae	0.37+/-0.40	0.56+/-0.97	0.91+/-1.06	0.09+/-0.37	0.1+/-0.23	0.41+/-0.42
Torrenticolidae	0.23+/-0.39	0.37+/-0.71	0.19+/-0.33	0.16+/-0.19	0.24+/-0.38	0.02+/-0.07
Valvatidae	0.09+/-0.22	0.07+/-0.16	0.26+/-0.41	0.05+/-0.16	0.12+/-0.34	0.04+/-0.10
Veliidae	0+/-0	0+/-0	0+/-0	0+/-0	0.05+/-0.13	0+/-0